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SPECIFICATION

5   METHOD AND APPARATUS FOR

PRECISION TUNING AN OPTICAL FILTER

USING A BALL-END JOINT

RELATED APPLICATIONS

10   This application is a continuation in part of US Applications Serial Number

09/617,736, filed July 17, 2000; and 09/713,634, filed Nov. 14, 2000. This application

also claims the benefit of US Provisional Application Serial Number 60/228,908, filed

Aug. 28, 2000.

BACKGROUND

15   Field

The present disclosure relates generally to fiber optics, and in particular, to a method and apparatus for precision tuning an optical element.

The Prior Art

Background

5   Optical filters formed using thin-film dielectric coatings are critical to the optical devices of today. As optical thin-film coating technologies improve, a greater array of optical filters is becoming available.

Figure 1 shows a diagram of a prior art optical filter. Typically, optical filters are formed on a large substrate, such as substrate 100 of FIG. 1. Substrate 100 may range in diameter from a

10   few to several centimeters, and may contain several laminates formed together to meet the desired specification. Depending on the type of laminates used, substrate 100 may range in thickness from 1 to 4 mm. Within substrate 100 several smaller dice are formed which represent individual optical filters, such as die 102 of FIG. 1. The individual die may be square, rectangular, or circular, and are typically 1-2 mm in diameter.

15   Manufacturers typically prepare optical filters to match a particular specification desired by a customer. One such specification is the center wavelength (CWL) of the filter. As is appreciated by those of ordinary skill in the art, the CWL is crucial to the operation of modern

optical devices, such as dense wavelength division multiplexers. Customers typically specify the CWL to be within +/- 50 pm to +/- 100 pm of the ITU grid.

However, such accuracy is very difficult for optical filter manufacturers to reach, and thus the yield of dice meeting a particular CWL is typically very low. In fact, a yield as low as 5-10%

5   is typical for a given substrate. Such a low yield has kept the price of thin-film filters relatively high.

Typically, the CWL for an optical filter is specified at the center of the filter. For example, manufacturers of devices such as thin-film filters typically specify the center wavelength only at the physical center of the filter. This is done because generally optical filters

10   are disposed within optical devices such that light is incident at the center of the optical filter. Thus, if the customer's desired specification is not met at the center of the filter, the filter will have to be rejected.

In an effort to increase the yield of optical filters, the prior art used the well known fact that the CWL of an optical filter is dependent in the angle of incident light. If an optical filter has

15   a CWL slightly out of specification, the optical filter may be angled to adjust the angle of incidence and thus the CWL of the filter. If the CWL was not too far out of specification, tilting the filter might bring the CWL of the filter back into specification.

However, tilting optical filters in applications such as dense wavelength division multiplexing is disfavored since the light reflected from the filter is often utilized as well as the

filtered light passing through the filter. If the filter is tilted in an attempt to adjust the CWL,

often the reflected light cannot be aligned correctly.

BRIEF DESCRIPTION

5   Methods and apparatus for tuning an optical element are disclosed. One aspect

comprises an optical element having a specified response at a predetermined location and means

for redirecting incident light to a location on the optical element other than the predetermined

location so as to achieve a desired response.

A portion of an optical device is disclosed which may comprise a cylinder and a module

10   having complimentary concave and convex surfaces so as to allow an optical element to be tuned

to desired response.

BRIEF DESCRIPTION OF THE DRAWING FIGURES

Figure 1 is a diagram of a prior art optical filter substrate.

15   Figure 2A is a diagram of illustrating the change in response of an optical element based

on the location of an incident beam of light.

Figure 2B is a end view of a portion of an optical device.

Figure 3A is a side view of a portion of an optical device.

Figure 3B is another diagram of a portion of an optical device.

Figure 4 is a diagram of a DWDM.

5   Figure 5 is a detailed cross section diagram of a portion of an optical device.

Figure 6 is an isometric diagram of a portion of an optical device.

Figure 7 is an isometric diagram of a portion of an optical device.

Figure 8 is a detailed isometric diagram of a portion of an optical device.

DETAILED DESCRIPTION

10   Persons of ordinary skill in the art will realize that the following description is illustrative

only and not in any way limiting. Other modifications and improvements will readily suggest

themselves to such skilled persons having the benefit of this disclosure. Like reference numerals

throughout are intended to designate substantially similar matter herein.

In one aspect of the disclosure, optical elements may be utilized to tune an optical device

15   by applying incident light to locations other than that specified by the manufacturer. For

example, the center wavelength of an optical device may be changed, or tuned, by applying light

to point incident on the surface of an optical element other than the center until a desired

response is achieved.

In FIG. 2A, an optical element 206 is shown over a graph showing the center wavelength

at corresponding locations on the surface of the optical element. When a thin-film filter is used as

5   the optical element, the center wavelength typically is highest (longest wavelength) at the center

of the filter. As the beam location is moved away from the center, the center wavelength

typically lowers. Thus, the center wavelength when measured at location 1 will typically be

higher than that measured at location 2.

In FIG. 2B a module 208 is shown having axes 300 and 302 which intersect at the center

10   of rotation of module 208. FIG. 2B further includes an optical element 206 having axes 302 and

304 which intersect at the optical element's center. The center of optical element 206 is marked

as position 1 in FIG. 2B. Optical element 206 may be positioned on module 208 such that the

center 1 of the optical element 206 is offset from the center of rotation of module 208. In one

aspect of a disclosed optical element, the center of optical element 206 may be offset from the

15   center of rotation of module 208 by a distance d.

Using the structure disclosed in FIGS. 2A and 2B, a method will now be disclosed

wherein the center wavelength of an optical element may be precision tuned by applying incident

light to different areas of an optical element.

With the optical element 206 attached to the module 208, the module 208 may then be rotated about its center of rotation. If light is being applied to the optical element 206 while the module 208 is rotated, the incident beam of light will be incident at different locations on the surface of the optical element 206. As the module 208 is rotated about its axis, the incident beam

5   of light will trace a path 306 on the surface of optical element 206.

As the apparatus is being rotated, the output of the optical element under test may be monitored to determine the center wavelength at a particular location. When a desired response is determined, the precise location may be noted for future use.

It is contemplated that the path 306 may be caused to trace a variety of paths or shapes.

10   As can be seen in FIG. 2B, the applied light may be along the surface of the optical element 206 such that a circle is formed. In one aspect of the disclosed optical element, one portion of the path 306 will lie on the center of the optical element 206. However, it is contemplated that the incident light may be applied to the surface of the optical element in any desired shape to any desired location on the surface of the optical element 206 such that a desired response is

15   obtained.

Many filters will maintain a proper response shape, even when the light is incident at a location offset from the filter's center. Thus, using the teachings of the present disclosure, a filter which previously may have been rejected as being out of specification may still be made usable

by applying light elsewhere on the surface of the filter, and tuning the filter to a particular ITU

grid while maintaining a proper response shape.

Throughout path 306 on the surface of optical element 206, different locations along the

path 306 may have different responses, such as center wavelengths. Thus, by rotating the

5   optical element 206 about the path 306, a predetermined response, such as a desired center

wavelength, may be chosen. However, it is contemplated that any characteristic of an optical

device may be tuned using the teachings of the present disclosure.

Referring now to Figure 3A, an optical device 200 is shown including a module 208.

Module 208 may comprise a wide variety of materials and shapes suitable for holding or securing

an optical element. Module 208 may be formed about an axis 210 which defines an axis of

rotation.

Device 200 further includes an optical element 206. Optical element 206 may comprise a

wide variety of optical elements in the art which may be precisely aligned. Optical element 206 is

further formed about an axis 212, which defines the physical or specified center of optical

15   element 206.

Optical element 206 may be affixed to module 208 such that the axis 212 of optical

element 206 is substantially parallel to, but not directly overlapping, the axis 210 of module 208.

Thus, axes 210 and 212 may be separated by a distance d. Incident light 205 may be applied

along axis 212 of optical element 206. Thus, the incident light 205 may be offset from the axis

210 of module 208 by a distance d.

In one aspect of a disclosed optical element, axis 212 and axis 210 may be separated by a

distance of 120 μm, creating a total shift about the surface of the optical element of

5   approximately 240 μm when rotated about a circle, yielding a tuning capability of approximately

200pm of continuous tunability. As will be appreciated by those of ordinary skill in the art, the

amount of distance d will depend on the particular application and desired tunability.

A more detailed example of means for redirecting light incident light will now be disclosed.

FIG 3B shows an optical device 201 including a pigtail 202 disposed along axis 210.

10   Pigtail 202 may comprise a fiber pigtail known in the art. The pigtail 202 further includes a

transmitting end 203 in which a wedge having an angle α has been formed for redirecting light at

an angle. Pigtail 202 may include wedge angles standard in the art, such as 8° or 12°. However,

the angle may be chosen based upon the offset distance d desired in a particular application.

A lens 204 is disposed along axis 210. Lens 204 may comprise any lens known in the art

15   suitable to accept light incident from transmitting end 203 of pigtail 202 and direct the light a

predetermined distance from axis 210. Lens 204 may be configured to align light along axis 212.

Pigtail 202 and lens 204 provide examples of means for offsetting or directing light along a

predetermined path. However, it is contemplated that a wide variety of configurations are

possible using optical elements known in the art to accomplish the task of directing light to predetermined offset as shown in FIG. 3B.

The disclosed optical element may be utilized wherever precise alignment and tuning of an optical element is needed. For example, any optical device that must be precisely aligned may

5   benefit from the present disclosure. For example, any multiplexer or demultiplexer in which an optical element such as a filter must be precisely aligned will benefit from the present disclosure. Additionally, the present disclosure may be utilized with other type of optical filters, such as longpass, shortpass, and wideband, etc.

A more detailed description of an optical device suitable for tuning an optical element in

10   accordance with the present disclosure will now be disclosed.

Figure 4 shows an optical device 400 including a first collimator 402 formed in a cylindrical shape about axis 408. First collimator 402 further has a first end 405 and a second end 424. The elements of optical device 400 may be fabricated from materials known in the art, such as stainless steel.

15   First collimator 402 further includes a ferrule 404 comprising elements known in the art, including an incident fiber 410 optically configured to receive incident optical signals, and a reflecting fiber 412 optically configured to transmit optical signals reflected by device 400. Ferrule 404 may be disposed between first end 405 and second end 424 along axis 408.

First collimator 402 further includes a lens 406 disposed between first end 405 and second end 424 along axis 408 optically coupling signals with ferrule 404. It is contemplated that many different types of lenses known in the art may be employed in the present invention, such as GRIN lenses, or aspherical lenses.

5   Optical device 400 further includes a filter module 428. Filter module 428 is preferably formed in a cylindrical shape about axis 408, and has a first end 430 and a second end 431. Filter module 428 includes a thin-film filter 426 disposed between first end 430 and second end 431 about an axis 427 which is offset from axis 408. It is contemplated that wide variety of optical elements known in the art may be employed in the present invention, such as GRIN lenses,

10   spherical or aspherical lenses, band pass filters, long or short pass filters, or selective filters. Filter 426 is disposed proximate to first end 430 and is configured to optically couple signals with lens 406. Additionally, means for redirecting the path of incident light may disposed proximate to filter 426 as described above.

       Optical device 400 includes a second collimator 416, which is preferably formed in a

15   cylindrical shape about axis 408. Second collimator 416 further includes a ferrule 420 comprising elements standard in the art, including a transmitting fiber 410 optically configured to couple optical signals to device 400. Ferrule 404 may be disposed within ferrule 420 along axis 408.

Device 400 further includes a lens 418 disposed along axis 408 and configured to optically couple signals with filter module 428. Lens 418 may comprise an aspherical lens as described above.

5   As mentioned above, the alignment and securing of filter 426 is critical to the operation of an optical device. The present disclosure provides a novel and useful solution which allows the precise placement and alignment of filter 426. As can be seen by inspection of FIG. 4, the second end 424 of first collimator 402 is formed so as to define a segment of an inward-facing concave spherical surface. Likewise, first end 430 of filter module 428 is formed so as to define a segment of an outward-facing convex spherical surface, with the convex surface being

10   complimentary in shape to the concave surface. The concave and convex surfaces allow an optical element, such as a filter, to be rotated with respect to the center of rotation, thereby applying light to different locations on the surface of the optical element. By so rotating the module, the response of the optical element may precisely tuned.

Figure 5 is a detailed cross-sectional diagram of a portion of an optical device focusing on

15   the concave and convex surfaces. FIG. 5 shows the second end 424 of first collimator 402, and the first end 430 of filter module 428. FIG. 5 shows filter 426 disposed within second end 430 about an axis 427 which is offset from axis 408. The material which forms the cylinder of first collimator 402 has been removed at second end 424 to form segments of an inward-facing spherical surface having a radius of R, and the material which forms the walls of filter module 428

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at first end 430 has been removed to form segments of an outward-facing spherical surface having

a radius of R.

Referring now to FIG. 6, an isometric view of a portion of an optical device is shown,

looking towards the first end of filter module 428 along axis 408, and includes a cross section

5   taken through second end 424 of first collimator 402. FIG. 6 also shows a ferrule 434 emanating

from first collimator 402. Ferrule 434 may include incident fiber 410 and reflecting fiber 412.

FIG. 6 also includes filter 426 disposed along axis 427, which is offset from axis 408.

FIG. 6 also shows how the material which forms the cylinder walls of first collimator 402

has been removed at second end 424 to form segments of an inward-facing spherical surface, and

10   how the material which forms the walls of filter module 428 at first end 430 has been removed to

form segments of an outward-facing spherical surface. The isometric view of FIG. 6 also shows

how the complimentary surfaces of the filter module and collimator allow the two to be mated.

Referring now to FIG. 7, an isometric view of a portion of an optical device is shown,

looking towards the second end of first collimator 402 along axis 408. FIG. 7 also includes a

15   cross section taken through second end 424 of first collimator 402. FIG. 7 also shows a ferrule

434 emanating from first collimator 402.

FIG. 7 again shows how the material which forms the cylinder walls of first collimator

402 has been removed at second end 424 to form segments of an inward-facing spherical surface.

Likewise, as can be seen by inspection of FIG. 7, the material which forms the walls of filter

module 428 at first end 430 has been removed to form segments of an outward-facing spherical surface, allowing the complimentary surfaces of the filter module and collimator to be mated.

Referring now to Figure 8, an isometric view of an optical device is shown including a cross section of the first collimator 402, illustrating the operational advantages of the present

5   invention.

FIG. 8 again shows how the material which forms the cylinder walls of first collimator 402 has been removed at second end 424 to form segments of an inward-facing spherical surface. Likewise, as can be seen by inspection of FIG. 8, the material which forms the walls of filter module 428 at first end 430 has been removed to form segments of an outward-facing spherical

10   surface. The isometric view of FIG. 8 also shows how the complimentary surfaces of the filter module and collimator allow the two to be mated. FIG. 8 also includes filter 426 disposed along axis 427, which is offset from axis 408.

During manufacturing, it is contemplated that module 428 will be placed in a jig with its first end 430 facing upwards. Then, the first collimator 402 may be placed over module 428 with

15   second end 424 facing downward. Thus, first end 430 of filter module 428 is mated with the second end 424 of first collimator 402 where the two may be moved relative to each other while still maintaining surface-to-surface contact. The operator may then precisely align the filter 426 by sliding the filter module 428 within the ball-end joint formed by the complimentary surfaces of first end 430 and second end 424 and choose a center wavelength.

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As mentioned above, the alignment of filter 426 is critical to the operation of optical devices. As can be seen by inspection of FIG. 8, the face of filter 426 forms a plane which intersects axis 408. Thus, the face of the filter 426 is afforded two degrees of freedom while still maintaining surface-to-surface contact. Thus, the plane formed by the face of filter 426 may be

5   aligned with respect to axis 408 at a predetermined angle.

More specifically, filter module 428 may be rotated about axis 408 by an angle φ. By rotating filter module 428 about axis 408, the optical element disposed within the filter module along an axis 427 will have incident light strike different locations on its surface, thereby tuning an optical element. This ability to maneuver the filter 426 is a significant advance over prior art

10   devices.

It is contemplated that wide variety of optical elements known in the art may be employed, such as band pass filters, long or short pass filters, or selective filters. It is contemplated that the present disclosure may be useful in applications such as DWDM applications where the center wavelength is critical, and optical beam splitters, where the band

15   splitting wavelength is critical. Therefore, the present disclosure should not be limited by the type of optical element employed.

While embodiments and applications of this disclosure have been shown and described, it would be apparent to those skilled in the art that many more modifications than mentioned above

are possible without departing from the inventive concepts herein. The disclosure, therefore, is not to be restricted except in the spirit of the appended claims.